Institution: University of Liverpool		
Unit of Assessment: 8		
Title of case study: High Throughput Polymer Discovery through the Centre for Materials Discovery		
Period when the underpinning research was undertaken: 2000 to Current		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. Andrew Cooper Prof. Steve Rannard	Professor Professor	1999 – current 2005 – current
Period when the claimed impact occurred: 01/08/2013 – 30/12/2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

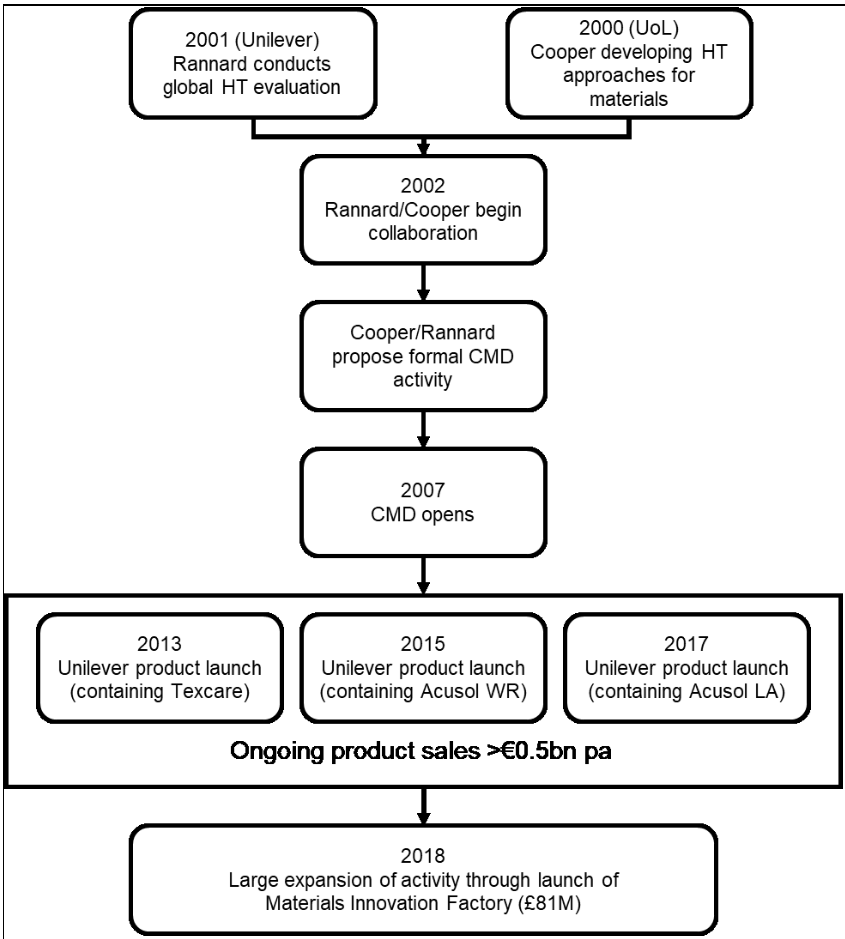
The academic-led Centre for Materials Discovery (CMD, University of Liverpool, Chemistry) ran from 2007 until the 2017 launch of the £81 M Materials Innovation Factory (MIF), into which the CMD capability was subsumed. Automated material discovery programmes in the CMD delivered impacts on commerce and the economy as demonstrated by:

(i) Materials developed in the CMD generated product sales (>€500 M p.a. 2018 - current).
(ii) A doubling in productivity for industrial scientists embedded in the CMD.
(iii) Significant acceleration of molecule discovery to product launch (< 2 yrs), leading to 3 global product launches during the REF period (Q4 2013, 2015, 2017).
(iv) New collaborative strategies being adopted globally by CMD industrial partners.

2. Underpinning research

The CMD (Cooper, Director) was an academic-led facility that was developed to accelerate the identification, development, and testing of new materials. At the CMD core was a 1600 m^2 open-plan high-throughput laboratory with robotic synthesis, formulation, and automated analytical facilities. The scientific methodologies deployed and the specialist high-throughput equipment of the CMD was enabled by the underpinning body of research and established academic excellence in materials and automated/high throughput chemistry of Cooper and Rannard [references 3.1–3.7].

Specifically, from 2000 onwards, the academic research of Cooper in chemistry delivered advances in the core areas of high throughput apparatus and accelerated/combinatorial studies, polymer chemistry and surfactant chemistry [3.1–3.4]. During this period, a productive collaboration between Cooper and Rannard (2002, then Unilever) was also established to expand their joint interest in automated materials chemistry [22 publications in total represented by references 3.6, 3.7]. The aim was to move beyond traditional combinatorial approaches based on random materials screening to a hypothesis-led focussed screening of smaller numbers of materials (10s–100s) at much higher mass per sample (gram scale). In the workflows that they developed, the increased mass per sample enabled accurate characterisation of samples prior to performance evaluation, which delivered discoveries in a faster and more reproducible way than traditional approaches. At the same time, the large number of well characterised samples produced allowed for the identification of subtle structure-function relationships in systems with interdependent variables [*e.g.*, 3.1]. This methodology, using customised, and in some cases home-built [3.1, 3.7], high throughput



platforms, became the core concept of the CMD, as demonstrated in reference [3.7]. Here, the effect of end-group composition on the lower critical solution temperature and solution composition for libraries of phase change polymers was studied using custom designed high throughput apparatus. Alongside the methodology development, research on rapid synthesis [3.2, 3.7] and characterisation [3.1, 3.3] also provided new automated platforms and capabilities for the CMD. The underpinning body of research was funded by a range of EPSRC grants to Cooper including "High-Throughput Discovery of Next-Generation CO_2-Philic Polymers" (GR/S16744/01) and a Royal Society Industrial Fellowship (2005) held at the University of Liverpool, Department of Chemistry, by Rannard.

Recognising the potential impact of this approach on both academic and industrial materials research, Cooper and Rannard sought financial support for the CMD. The CMD was established in 2007 following a successful proposal supported by the ERDF, the NW Development Agency, and joint funding from the University of Liverpool and Unilever (£11 M total). Prior to funding the project, Unilever carried out a "*comparative analysis of other internationally available academic teams who were active in advanced materials, chemistry and formulation*" to identify partners to co-develop new approaches to automated materials discovery [Evidence 5.1, letter from the VP Science and Technology, Unilever Home Care R&D] leading to the choice of the Department of Chemistry at Liverpool. The Centre was available to other industrial collaborations across materials and chemical sciences including the identification of novel catalysts using underpinning CMD approaches. The CMD would not have been funded (and by extension, the present Materials Innovation Factory) without the excellence and body of academic research in accelerated synthesis, characterisation and testing [3.1–3.6] that was generated by Cooper and Rannard within Chemistry at Liverpool.

3. References to the research

[**1**] High-throughput solubility measurements of polymer libraries in supercritical carbon dioxide, CL Bray, B Tan, CD Wood, AI Cooper, *J. Mater. Chem.* **2005**, *15*, 456, published online Nov 2004, DOI:10.1039/B415343J, 37 citations

[**2**] Combinatorial microwave synthesis of nanoporous poly(arylene ethynylene)s, AI Cooper et al. Conference paper, ACS national meeting, POLY-159 (2008).

[3] Polymer synthesis using hydrofluorocarbon solvents. 1. Synthesis of cross-linked polymers by dispersion polymerization in 1, 1, 1, 2-tetrafluoroethane, CD Wood, K Senoo, C Martin, J Cuellar, AI Cooper, *Macromolecules*, **2002**, *35*, 6743, DOI:10.1021/ma025506b, 26 citations
[4] Combinatorial discovery of reusable noncovalent supports for enzyme immobilization and nonaqueous catalysis, J Long, GA Hutcheon, AI Cooper, Combinatorial Chemistry, *J. Comb. Chem.*, **2007**, *9*, 399-406, DOI:10.1021/cc060121g, 6 citations
[5] Aligned two- and three-dimensional structures by directional freezing of polymers and nanoparticles, SP Rannard, AI Cooper et al., *Nature Mater.*, **2005**, *4*, 787, DOI: 10.1038/nmat1487, 539 citations.
[6] Formation and enhanced biocidal activity of water-dispersible organic nanoparticles AI Cooper, SP Rannard et al., *Nature Nano.*, **2008**, *3*, 506, DOI:10.1038/nnano.2008.188, 112 citations.
[7] Structure–LCST relationships for end-functionalized water-soluble polymers: an “accelerated” approach to phase behaviour studies, SP Rannard, AI Cooper et al., *Chem. Commun.* **2007**, 2962, DOI:10.1039/B702067H, 31 citations.

4. Details of the impact

Between 2007 and 2017, the CMD co-located academic and industry staff in an “open-collaboration environment”, providing industry partners with access to academic-led bespoke facilities, equipment and expertise. Unilever was a founding partner of the CMD and substantial impacts on commerce and the economy have been generated during the REF period through the Liverpool Chemistry–Unilever collaboration. This impact is demonstrated through:

- The sales of new consumer products based on polymers discovered (>€500 M pa)
- A doubling in productivity of industrial scientists embedded in the CMD
- A change in business practice for a multinational company, Unilever, and adoption of new processes, creating the confidence ultimately to invest in the £81 M Materials Innovation Factory.

A case-study from the University of Lancaster examined open-innovation within the Unilever Structured Materials & Process Science Expertise Group. In this study, the Vice President Science and Technology (Unilever Homecare) explained how the company collaborated and benefitted from the academic expertise in advanced materials of Cooper: *“what Liverpool do provide uniquely here is evoking that facility to be the best in the world in its area and to be able to help us to be good enough to utilise it to its capability. What we bring is the knowledge of our consumers and our brands and our challenges to turn that stuff into things we can then turn into technologies that benefit consumers”* [5.2]

New product discovery and increased revenue: The CMD has delivered economic impact through the discovery of new molecules leading to multiple global product launches by Unilever as a result of collaborative work within the CMD with Cooper on high-throughput methodologies and polymer chemistry. “*Unilever has benefitted from collaborative work at the CMD in the area of polymer research, leading to a number of newly synthesised molecules. This included Texcare UL (a laundry soil release polymer, commercialised in 2013), Acusol WR (a thickening polymer commercialised for launch in EU flagship laundry liquid in 2015) and Acusol LA (a thickening polymer commercialised in 2017)”* [5.3].
These three global product launches have led to substantial sales within the REF period which are described as “*of a significant economic scale to Unilever* (2018 turnover >€51 Bn) *and its*

commercialization partners" [5.1, point 6]. Revenue figures from one product launch alone have "*increased rapidly over a 3 year period from first launch [2015] to exceed €0.5 Bn per annum of recurring revenue*" [5.1, point 7]. Commercial sensitivity prevents disclosure of the polymer structure and full value, but Unilever confirm that the polymer which is incorporated into the product is vital for its manufacture and performance and was derived directly from IP created at the CMD. [5.1 point 7].

This case focuses on the impact arising from the Unilever-University of Liverpool collaboration in the CMD, but we highlight that access to the CMD was not restricted to Unilever; >80 companies benefited from collaboration with the CMD, with 12 of these interactions occurring during the REF period ranging from SMEs to large multinationals [5.4]. IP was retained by the partner companies, allowing for de-risking of commercially sensitive activities within an academic facility. Non-Unilever projects led to a filing of 36 new patents and 9 patent families that are currently active (October 2020) the maintenance of which can be reasonably interpreted to indicate economic value and commercial impact.

Increased productivity and reduced time to market:

The workflow and customised high-throughput platforms developed by Cooper and Rannard, demonstrated in [3.1, 3.2, 3.7], have led to a step-change in the way that Unilever undertakes materials discovery and to unprecedented short timescales to market for new products [5.1, point 1]. This is confirmed in the support letter which states "*The incorporation of the CMD into our R&D process has led to a significant acceleration of our end-to-end innovation speed*", [5.1, point 6]. Furthermore, the Vice-President for Open Innovation has stated: "*The University [Liverpool] has enabled a transformation in the way Unilever approaches a traditional and established field such as chemistry*". [5.5] Products containing Acusol WR were launched less than 2 years after the concept for the molecule was initially proposed [5.1, point 7]. This represents a remarkable idea-to-innovation timescale for the chemistry industry, giving CMD users a significant commercial advantage. The speed of development of Acusol WR was a direct result of the high-throughput, hypothesis-led approaches and the automated facilities of the CMD, which allowed for a far greater volume of studies to be carried out compared to conventional manual approaches. The automated systems were applied during the initial discovery stages and they also facilitated the scale up studies carried out at the CMD by Unilever supply chain partners (Dow chemicals) during product development [5.1, points 6,7]. The improved productivity of embedded scientists within the CMD also led to a doubling of patent outputs per researcher [5.6]. Until its replacement by the Materials Innovation Factory (MIF) in 2017, Unilever had 10 flexible research seats within the CMD, allowing rotation of numerous scientists to benefit from the facility and academic expertise. The supporting letter confirms the gain in productivity and links this to the automated synthesis and testing developed in the body of underpinning work described in section 1: "*Unilever employees we located in the CMD labs at the University of Liverpool were able to make a step change in their productivity and delivery to business led R&D programs, The shift from 100% manual working to fully integrated lab automation and rapid testing has enabled significant skills growth in individuals, and also across the wider teams they are part of.*" [5.1, point 5].

Business strategy – the "Liverpool Model": Unilever is a multinational FMCG company (with a research budget of ~€1Bn p.a.) with 6000 staff world-wide in R&D [5.7]. The CMD has led Unilever to change their working practices world-wide. The VP for Science and Technology, Unilever Home Care R&D states in his 2020 letter that "*In addition to the specific impacts the CMD has had on materials discovery, the approach has had a profound impact* *on Unilever R&D internal practices, our focus on Innovation Ecosystems, and our approach to working with academic groups globally*." [5.1, point 3].

Unilever has articulated the "Liverpool Model" at numerous UK events and has encouraged its adoption more widely. The Liverpool model is based upon its experiences of interacting with Cooper and the CMD. It describes the benefits of basing an investment and strategic partnership at sites of academic thought leadership where differentiated research cultures, methodologies, and equipment platforms can be developed and jointly exploited [5.1, point 4]. In line with this approach of investing at sites with demonstrable bodies of outstanding academic expertise, Unilever made a £25 M investment into the Materials Innovation Factory (MIF) at the University of Liverpool, their largest single investment in academic R&D in the 150-year history of Unilever. The £81 M MIF opened in 2017 and co-locates academic groups from chemistry (including Cooper & Rannard) alongside up to 100 industrial researchers to exploit the automated, high-throughput materials synthesis and testing approaches developed at Liverpool, alongside new, emerging approaches such as mobile robots (Cooper), ensuring that the original ethos of the CMD continues into the future.

5. Sources to corroborate the impact

5.1. Letter from Vice-President for Science and Technology, Unilever Home Care R&D. The letter confirms the development of new products, sales and impact on Unilever business mode as a result of the CMD. The letter also states that the CMD arose as a result of the leading academic research in advanced materials, chemistry and formulation at Liverpool Chemistry, 27/01/2020.

5.2. M. Decter, et al., "Access is the new ownership: a case study of Unilever's approach to open innovation", Institute of Entrepreneurship and Enterprise Development, University of Lancaster, 2010

5.3. Unilever presentation on University of Liverpool-Unilever relationship. Slide 14 names new CMD products developed in collaboration with Cooper at the CMD. Available at https://prezi.com/p/scujlq0hcv4j/mif-timeline/, accessed 19/10/20

5.4. List of companies who benefitted from the CMD during the REF period and list of known patents filed during CMD lifetime.

5.5. Press release with statement from the Unilever Vice-President for Open Innovation containing quote given in text, available at *https://www.liverpool.ac.uk/cooper-group/news/articles/universitys-chemists-enable-unilever-to-improve-household-products*, accessed 19/10/20

5.6. Thesis, "Case study of a university-industry partnership (UIP) in science and technology: What drives extraordinary performance?", Neil J. Campbell, 2017, University of Liverpool. Pg 174 contains interview with Unilever Senior Innovation Executive confirming doubling of patent output and productivity.

5.7. Budget for R&D and number of employees in R&D for Unilever, available at https://www.unilever.co.uk/about/innovation/innovation-in-unilever/, accessed 19/10/20.